



UNIVERSITI PUTRA MALAYSIA

**PREDICTING SULPHUR DIOXIDE DISPERSION ISOPLETHS FROM
MULTIPLE INDUSTRIAL SOURCES IN SEBERANG PERAI USING
THE STEADY STATE GAUSSIAN PLUME MODEL**

NURUL SULIANA BINTI AHMAD HAZMI

FPAS 2006 3

**PREDICTING SULPHUR DIOXIDE DISPERSION ISOPLETHS FROM
MULTIPLE INDUSTRIAL SOURCES IN SEBERANG PERAI USING
THE STEADY STATE GAUSSIAN PLUME MODEL**

By

NURUL SULIANA BINTI AHMAD HAZMI

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirement for the Degree of Master of Science**

November 2006



To Mom and Dad, thanks for hanging in there through everything. I will never get this far without your support. To my brother and sister, thanks for always understanding and never-ending love.

And especially to all my friends, your help and encouragement have been so valuable to me. Hope the future holds something wonderful for all of you.



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment
of the requirement for the degree of Master of Science

**PREDICTING SULPHUR DIOXIDE DISPERSION ISOPLETHS FROM
MULTIPLE INDUSTRIAL SOURCES IN SEBERANG PERAI USING THE
STEADY STATE GAUSSIAN PLUME MODEL**

By

NURUL SULIANA AHMAD HAZMI

November 2006

Chairman : Associate Professor Ahmad Makmom Hj. Abdullah, PhD

Faculty : Environmental Studies

Air quality modeling is an essential tool for most air pollution studies and the introduction of SO₂ standards creates a need for modeling the dispersion of SO₂. This work deals specifically with the use of the Steady State Gaussian Plume Model at Seberang Perai Industrial Area, Penang. The study utilized air quality data which span over a period of 5 years (1999-2003). The first objective of this study was to simulate SO₂ dispersion isopleths from multiple industrial sources at Seberang Perai Industrial Area which contributed to at least 70-75% of the total air pollution load in Penang. The second objective was to evaluate the Steady State Gaussian Plume Model by comparing the calculated and measured concentrations. The results showed that both simulated and measured concentrations are within a factor of 2, judged to be validated when the calculated and measured values do not differ in the annual averages by more than approximately 30% and the hourly concentration with 95% of the accumulative frequency distribution. Hence, Steady State Gaussian Plume Model employed by ISCST

(design by the U.S EPA) is verified and is suitable for simulating air pollutants dispersion from industrial activities in this country. The dispersion isopleths obtained in this study confer the first dispersion isopleths in Seberang Perai and formed a basis study for future scenarios that include the impacts of increasing energy consumption per capita, of changing populations and of new industrial development, including their optimal siting.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai keperluan untuk ijazah Master Sains

RAMALAN PENYEBARAN ISOPLET SULFUR DIOKSIDA DARI BERBILANG SUMBER INDUSTRI DI SEBERANG PERAI MENGGUNAKAN MODEL KEADAAN MANTAP PLUM GAUSSIAN

Oleh

NURUL SULIANA AHMAD HAZMI

November 2006

Pengerusi : Profesor Madya Ahmad Makmom Hj. Abdullah, PhD

Fakulti : Pengajian Alam Sekitar

Pemodelan kualiti udara adalah merupakan satu kaedah bagi kebanyakan kajian pencemaran udara dan kewujudan standard SO_2 menjadi faktor utama keperluan kepada pemodelan SO_2 . Kajian ini di jalankan di Kawasan Perindustrian Seberang Perai, Pulau Pinang dengan menggunakan Model Keadaan Mantap Plum Gaussian bagi tempoh 5 tahun (1999-2003). Objektif pertama kajian adalah bagi menghasilkan penyebaran isopleth SO_2 dari pelbagai sumber industri di Kawasan Perindustrian Seberang Perai; yang menyumbang kepada 70-75% jumlah keseluruhan pencemaran udara di Pulau Pinang. Objektif kedua adalah bagi menilai Model Keadaan Mantap Plum Gaussian dengan membezakan kepekatan data simulasi dengan data kajian lapangan. Hasil kajian menunjukkan perbezaan kedua-dua bacaan adalah di bawah faktor gandaan 2, yang mana disahkan benar apabila kepekatan data simulasi dengan data kajian lapangan tidak berbeza purata tahunannya dengan anggaran 30% dan kepekatan bacaan setiap jam

adalah 95% dari taburan frekuensi akumulatif. Oleh itu, Model Keadaan Mantap Plum Gaussian yang digunapakai dalam ISCST (direkabentuk oleh USEPA) juga adalah sesuai digunakan di negara ini bagi tujuan simulasi sebaran reruang bahan pencemar dari kawasan industri disamping dapat menjimatkan masa, menjangkakan kejadian yang tidak diingini serta dapat mengurangkan kos perlaksanaan operasi. Hasil kajian ini adalah yang pertama seumpamanya dalam penghasilan simulasi sebaran reruang bahan pencemar di Seberang Perai dan akan menjadi asas utama bagi kajian selanjutnya.

ACKNOWLEDGEMENTS

Financial support for this research was provided by the Ministry of Science, Technology and Innovation (grant 08-02-04-0613 EA001) and National Science Fellowship (NSF) award.

The author is indebted to Assoc. Prof. Dr. Ahmad Makmom Hj. Abdullah, Dr. Marzuki Hj. Ismail, Assoc. Prof. Dr. Azizi Muda and Assoc. Prof. Dr. Wan Nor Azmin Sulaiman for their encouragement and valuable comments in carrying out this research. They greatly contributed to the improvement of this work.

The author acknowledges assistance from the Malaysian Meteorological Department, which provided the meteorological data and Municipal Council of Seberang Perai and also Department of Agricultural for providing land use and land cover map. Special thanks are also due to Ir. Dr. Shamsudin Ab. Latif from the Department of Environment for providing the access on the source information and ambient air pollution data in the area.

Sincere thanks also go to Mr. Marzuki Mokahtar and Mr. Zulfatah Yaacob, who helped to prepare many data tables and figures. The author wishes to convey her thanks to her adored family for their support and to the reviewers for suggesting improvements to this research. Their valuable comments are greatly appreciated.

I certify that an Examination Committee met on the 27th November 2006 to conduct the final examination of Nurul Sulfiana Binti Ahmad Hazmi on her Master of Science thesis entitled “Predicting Sulphur Dioxide Dispersion Isopleths From Multiple Industrial Sources in Seberang Perai Using the Steady State Gaussian Plume Model” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Act 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Puziah Abdul Latif, PhD

Lecturer
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Muhammad Firuz Ramli, PhD

Lecturer
Faculty of Environmental Studies
Universiti Putra Malaysia
(Internal Examiner)

Helmi Zulhaidi Mohd. Shafri, PhD

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Nik Meriam Nik Sulaiman, PhD

Professor
Faculty of Engineering
Universiti Malaya
(External Examiner)

HASANAH MOHD. GHAZALI, PhD

Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 22 MARCH 2007

Saya mengesahkan bahawa Jawatankuasa Peperiksaan Tesis bagi Nurul Suliana Binti Ahmad Hazmi telah mengadakan peperiksaan akhir pada 27 November 2006 untuk menilai tesis Master beliau yang bertajuk “Ramalan Penyebaran Isoplet Sulfur Dioksida Dari Berbilang Sumber Industri Di Seberang Perai Menggunakan Model Keadaan Mantap Plum Gaussian” mengikut Akta Universiti Pertanian Malaysia (Ijazah Lanjutan) 1980 dan Peraturan-peraturan Universiti Pertanian Malaysia (Ijazah Lanjutan) 1981. Jawatankuasa Peperiksaan Tesis memperakukan bahawa calon ini layak dianugerahi ijazah tersebut. Ahli Jawatankuasa Peperiksaan Tesis adalah seperti berikut:

Puziah Abdul Latif, PhD

Pensyarah
Fakulti Pengajian Alam Sekitar
Universiti Putra Malaysia
(Pengerusi)

Muhammad Firuz Ramli, PhD

Pensyarah
Fakulti Pengajian Alam Sekitar
Universiti Putra Malaysia
(Pemeriksa Dalam)

Helmi Zulhaidi Mohd. Shafri, PhD

Pensyarah
Fakulti Kejuruteraan
Universiti Putra Malaysia
(Pemeriksa Dalam)

Nik Meriam Nik Sulaiman, PhD

Profesor
Fakulti Kejuruteraan
Universiti Malaya
(Pemeriksa Luar)

HASANAH MOHD. GHAZALI, PhD

Profesor/Timbunan Dekan
Sekolah Pengajian Siswazah
Universiti Putra Malaysia

Tarikh: 22 MAC 2007

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

Ahmad Makmom Abdullah, PhD

Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Azizi Muda, PhD

Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

Wan Nor Azmin Sulaiman, PhD

Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

AINI IDERIS, PhD

Professor/Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I hereby declare that the thesis is based on my original work except for quotation and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NURUL SULIANA AHMAD HAZMI

Date: 22 FEBRUARY 2007

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	xi
LIST OF TABLES	xiv
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xviii
 CHAPTER	
 1 INTRODUCTION	 1
1.1 The need for air pollution modeling	3
1.2 Problem statement	5
1.3 Scope and limitation of the study	8
1.4 Objectives of the study	8
1.5 Hypotheses	10
1.6 Assumptions	11
1.7 Significance of the study	11
1.8 Structure of the thesis	12
 2 LITERATURE REVIEW	 13
2.1 Air quality monitoring and management in Malaysia	13
2.2 Ambient air quality monitoring	14
2.3 Air emission sources	15
2.3.1 Mobile source emissions	16
2.3.2 Stationary source emissions	16
2.3.3 Open burning source emissions	17
2.4 Air Pollutant Index (API) in Malaysia	17
2.4.1 An overview of air quality status of Seberang Perai, Penang (1996-2005)	19
2.5 Effects of air pollution on health	20
2.6 Sulfur dioxide	24
2.6.1 General description of sulfur dioxide	24
2.6.2 Sources of sulfur dioxide	25
2.6.3 Health and environmental effects of sulfur dioxide	26
2.6.3.1 Route exposure to human health	26
2.6.3.2 Guideline of sulfur dioxide	27
2.6.3.4 Environmental impacts of sulfur dioxide in Malaysia	30



2.7	Air pollution meteorology	31
2.7.1	Effect of wind regimes on dispersion	33
2.7.2	Turbulence	39
2.7.3	Temperature inversion	40
2.7.4	Lapse rate	41
2.7.5	Stability class	43
2.7.6	Plume type	45
2.7.7	Maximum mixing depth	48
2.8	Air dispersion modeling	51
2.8.1	Introduction	51
2.8.2	The Steady State Gaussian Plume Model	53
2.8.3	The Industrial Source Complex-Short Term (ISCST)	60
3	MATERIALS AND METHOD	63
3.1	Site description	63
3.3.1	Population	63
3.2	Research parameterization	68
3.2.1	Meteorological data	68
3.2.2	Input runstream data	72
3.2.2.1	Source location and parameter data	72
3.2.2.2	Receptor location	73
3.2.2.3	Output option	73
3.2.3	Simulation of the model	74
3.3	Ground level concentration monitoring	74
3.4	Statistical analysis	82
4	RESULTS AND DISCUSSIONS	83
4.1	Climate conditions in Penang	83
4.1.1	Rainfall	83
4.1.2	Temperature	85
4.1.3	Wind	86
4.2	Model performance evaluation during the ground level concentration (GLC)	93
4.3	Spatial distribution of SO ₂ concentrations	95
4.4	Sensitivity analysis	124
5	CONCLUSIONS AND RECOMMENDATIONS	126
	REFERENCES	130
	APPENDICES	142
	BIODATA OF THE AUTHOR	154
	LIST OF PUBLICATIONS	156

LIST OF TABLES

Table	Page
1 The existing land use in Seberang Perai, Penang, 1995 and 2005	7
2 Sulfur dioxide emission load from stationary sources	15
3 Recommended Malaysian Air Quality Guidelines (Ambient Standards)	18
4 Air Pollutant Index	19
5 Information on Criteria Pollutants	21
6 Exposure level of sulfur dioxide and health effects	28
7 Beaufort scale of wind speed equivalents	36
8 Municipal council which covers 3 administrative districts and places of Penang	65
9 Population size and composition for Penang Municipal Council, 2000	67
10 Observed concentration and the meteorological condition during the Experiment	75
11 Specification of basic meteorological condition of TG-501	80
12 Monthly Rainfall for Bayan Lepas Station (1999-2003)	84
13 Average Wind Speed at Bayan Lepas Upper Air Station, 1999-2003	88
14 Frequency of calm for Bayan Lepas Upper Air Station, 1999-2003	89
15 The comparison of field measurement and predicted by Steady State Gaussian Plume Model	94
16 The downwind distance concentration for SO ₂ under worst case scenario	123



LIST OF FIGURES

Figure		Page
1	SO ₂ concentration (ppm) at Seberang Perai Station from year 1996 until 2005	5
2	Land Use and Land Cover map of Seberang Perai, Penang	9
3	Air quality status at Seberang Perai from year 1996-2000	19
4	Wind speed and wind direction recorded at Bayan Lepas, 2003	34
5	Average vertical wind speed profiles over surfaces of varying roughness	37
6	Under condition of light regional winds and clear skies, the heating in the city causes the air to rise. Descent take place in the surrounding countryside	38
7	During light winds, hot gases in a plume can create a circulation which can cause pollution to loop down to ground level some distance from the source	39
8	Stability of an air parcel, determined by the environmental lapse rate	43
9	Six type of plume behavior under various condition of stability	47
10	Establishment of the maximum mixing depth (MMD) under various atmospheric conditions	49
11	Determination of afternoon mixing height from morning upper-air sounding and afternoon surface temperature	49
12	Gaussian plume from an elevated sources, effective stack height (H) is equal to the geometric stack height (h_s) plus the plume rise, δh	58
13	Horizontal dispersion, σ_y vs. downwind distance from source for Pasquill's turbulence type	57
14	Vertical dispersion, σ_z vs. downwind distance from source for Pasquill's turbulence type	57
16	Location of the study area	64
17	Close up of the study area	66

18	Key Summary Statistic for Penang Municipal Council, 2000	67
19	Research approach used in the study	69
20	On site measurement of SO ₂ ground level concentration	78
21	Garmin eTrex Venture GPS System	79
22	Electrochemical gas sensor; TG-501	81
23	Annual total rainfall for Bayan Lepas from 1999-2003	85
24	Yearly mean temperature for Bayan Lepas from 1999-2003	83
25	Monthly mean temperature for Bayan Lepas from 1999-2003	86
26	Annual wind rose pattern for Bayan Lepas from 1999-2003	90
27	Northeast monsoon wind rose pattern for Bayan Lepas from 1999-2003	91
28	Southeast monsoon wind rose pattern for Bayan Lepas from 1999-2003	92
29	Comparison of mean, x measured concentration at GLC with those predicted by Steady State Gaussian Plume Model	94
30	Isopleth of 1-hr simulation for SO ₂ from Seberang Perai Industrial Area for different monsoons during 1999	96
31	Isopleth of 1-hr simulation for SO ₂ from Seberang Perai Industrial Area for different monsoons during 2000	98
32	Isopleth of 1-hr simulation for SO ₂ from Seberang Perai Industrial Area for different monsoons during 2001	100
33	Isopleth of 1-hr simulation for SO ₂ from Seberang Perai Industrial Area for different monsoons during 2002	102
34	Isopleth of 1-hr simulation for SO ₂ from Seberang Perai Industrial Area for different monsoons during 2003	104
35	Plot of fitted model Scenario 1 for 1-hr SO ₂ concentration versus year	107
36	Plot of fitted model Scenario 2 for 1-hr SO ₂ concentration versus year	107
37	Isopleth of 24-hr simulation for SO ₂ from Seberang Perai Industrial Area for different monsoons during 1999	109

38	Isopleth of 24-hr simulation for SO ₂ from Seberang Perai Industrial Area for different monsoons during 2000	111
39	Isopleth of 24-hr simulation for SO ₂ from Seberang Perai Industrial Area for different monsoons during 2001	113
40	Isopleth of 24-hr simulation for SO ₂ from Seberang Perai Industrial Area for different monsoons during 2002	115
41	Isopleth of 24-hr simulation for SO ₂ from Seberang Perai Industrial Area for different monsoons during 2003	117
42	Plot of fitted model Scenario 1 for 24-hr SO ₂ concentration versus year	119
43	Plot of fitted model Scenario 2 for 24-hr SO ₂ concentration versus year	119
44	Near field receptor of SO ₂ ground level concentration	122
45	The surface plot of the concentration profile at 370m downwind distance	122
46	The surface plot of the concentration profile on worst case scenario	123
47	Maximum variation in predicted concentration	125

LIST OF ABBREVIATIONS

Air Pollutant Index	API
Air Quality Monitoring Stations	AQMS
Alam Sekitar Malaysia	ASMA
Analysis of Variance	ANOVA
Business as Usual	BAU
Carbon monoxide	CO
Department of Environment	DOE
Environmental Protection Agency	EPA
Environmental Quality Act	EQA
Geographical Information System	GIS
Health Risk Assessment	HRA
Industrial Source Complex Short Term	ISCST
Institut Latihan Prai	ILP
Jabatan Ukur dan Pemetaan Malaysia	JUPEM
Kuala Lumpur International Airport	KLIA
Lead	Pb
Malaysia Air Quality Index	MAQI
Malaysia Meteorological Station	MMS
Nitrogen dioxide	NO ₂
Non Government Organization	NGO
Ozone	O ₃

Particulate matter	PM
Pollutant Standard Index	PSI
Recommended Malaysia Air Quality Guideline	RMAQG
Sulfur dioxide	SO ₂
Suspended Particulate Matter	SPM
Total Suspended Particulate	TSP
United States of America	USA
United States Environmental Protection Agency	USEPA
Volatile organic compound	VOC
World Health Organization	WHO

CHAPTER 1

INTRODUCTION

Increasing air pollution levels due to rapid urbanization and growth in industrial emissions are now causes of major concern in many large cities of the world (Marsh and Foster, 1967; Martin and Barber, 1980; Katarina, 1993; Yadav and Kaushik, 1995; Jinliang et al., 2000; Ung et al., 2001; Desqueyroux et al., 2002; Manju et al., 2002; Bingheng et al., 2004; Graham, 2004; Yue et al., 2005; Panday et al., 2002, 2004, 2005; Filleul, 2005; Bhanarkar et al., 2005). When strategies to protect public health are under consideration, establishing ambient air quality standards and regulations have been introduced in order to set limits on the emissions of pollutants (United State Environmental Protection Agency, 1999). To achieve these limits, consideration was given to mathematical and computer modeling of air pollution. Therefore, air quality models are indispensable tools for assessing the impact of air pollutants on human health and the urban environment (Gokhale and Khare, 2004). The necessity for such models has increased tremendously especially with the rising interest in the early warning systems in order to have the opportunity to take emergent and preventive actions to reduce pollutants when conditions that encourage high concentrations are predicted (Perez, 2001). On the other hand, long-term forecasting and controlling of air pollution are also needed in order to prevent the situation from becoming worse in the long run. Such forecasting is especially important to sensitive group's i.e. children, asthmatics, pregnant women and elderly people (Tiitanen et al., 1999; Kolehmainen et al., 2001). The trend in recent years has been to use more statistical models instead of traditional

deterministic models (Kolehmainen et al., 2001). The statistical models are based on semi-empirical relations among available data and measurements (Gokhale and Khare, 2004). They depend on the statistical analysis of previous air quality data and do not necessarily reveal any relation between cause and effect. They attempt to determine the underlying relationship between sets of input data and targets. They have been used to establish an empirical relationship between air pollutant concentrations and meteorological parameters (Gokhale and Khare, 2004). They are quite useful in real time short-term forecasting. Examples of statistical models are regression analysis (Abdul-Wahab et al., 1996, 2003, 2005) time-series analysis (Hsu, 1992) and artificial neural networks (Gardner and Dorling, 1998; Abdul-Wahab, 2001; Elkamel et al., 2001; Abdul-Wahab and Al-Alawi, 2002; Nunnari et al., 2004). The generation of sulphur dioxide (SO_2) from a heavily industrialized area with several petrochemical complexes may affect the surrounding environment. SO_2 is formed primarily from the combustion of sulphur-containing fuels and can affect the health of the people. The introduction of SO_2 standards created a need for method of modeling the dispersion of SO_2 to assist in identifying areas at risk of exceeding the standards, identifying measures that could be taken to meet the standards, and predicting the economic impact of control measures (World Health Organization, 1999; 2000).

A model widely used for estimating atmospheric concentrations of a chemical, downwind from a source, is the Steady State Gaussian Plume Model. There are numerous research works that involve in estimating pollutant concentrations downwind from a multiple source utilizing the Steady State Gaussian Plume Model at different study areas

(Zannetti, 1983; Al-Sudairawi et al., 1988; Ramesh and Naperkoski, 1984; Dhari and Yehia, 1996; Abdul-Wahab, 2002; Morgan, 2003; Sivacoumar, 2001; Joshua et al., 2005).

In this paper, SO₂ dispersion isopleths were developed for predicting maximum SO₂ levels emitted from Seberang Perai Industrial Area, Penang. The aim was to determine the accuracy of Steady State Gaussian Plume Model by verifying the predicted concentration values with onsite measurements for SO₂ within a factor of 2. The effects of variations for meteorological parameters and physical parameters in the model that are expected to affect the SO₂ concentrations were investigated. They were wind speed, atmospheric stability class, wind direction, mixing height, ambient temperature, stack exit velocity, stack exit temperature and emission rate.

1.1 The need for air dispersion modeling

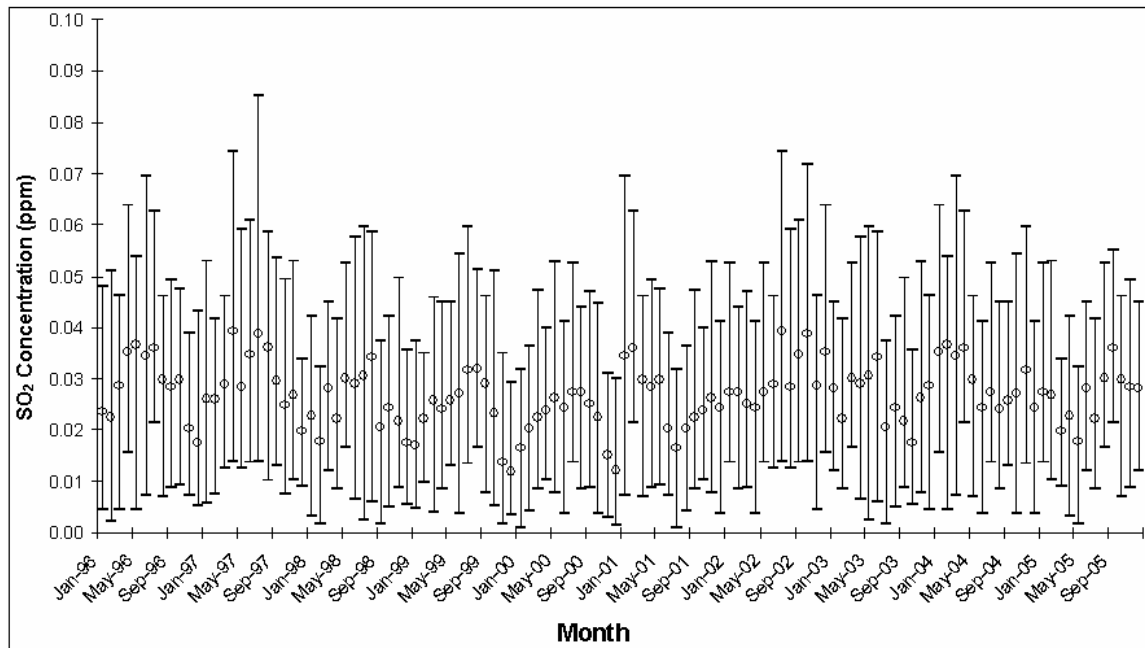
In establishing ambient air quality standards, regulations have been introduced in order to set limits on the emissions of pollutants (United State Environmental Protection Agency, 1999). To achieve these limits, consideration was given to mathematical and computer modeling of air pollution. Therefore, air quality models are indispensable tools for assessing the impact of air pollutants on human health and the urban environment (Gokhale and Khare, 2004). The necessity for such models has increased tremendously especially with the rising interest in the early warning systems in order to have the opportunity to take emergent and preventive actions to reduce pollutants when conditions that encourage high concentrations are predicted (Perez, 2001).

Air dispersion model is used to estimate the pollution concentrations attributable to a source or group of sources (World Health Organization, 2004; Minnesota Health State, 2004; United State Environmental Protection Agency, 2005). Air dispersion modeling can simulate a point and multiple source; a two-dimensional source (fugitive dust from a road that is wide and long); or a three-dimensional source (fugitive dust from a large coal pile that is wide, long and tall).

It is a way to mathematically simulate atmospheric conditions and behavior. It is usually performed using computer programs. Using inputs such as meteorological data and source emissions, air models can calculate pollutant concentrations in the air or the amount of pollutants deposited (deposition) on the ground. There are many kinds of air dispersion models, and an appropriate model is selected based on the type of analysis that is needed. Results of model simulation can predict the impacts of new sources before they are introduced and also allow an examination of the effects of different types of pollution controls before any actual changes are made to the sources of pollution. In addition, air dispersion modeling is sometimes used to locate air quality monitors in areas where high pollutant concentrations are most likely to occur. Besides, air pollution modeling can be used for stack design studies, combustion source permit applications, regulatory variance evaluation, monitoring network design and prevention of significant deterioration through planners and decision makers to estimate, for example; the increased risk of health problems in people who are exposed to different amounts of air pollutant. Hence, air dispersion modeling is necessary to provide timely provision for assessing downwind concentrations.

1.2 Problem statement

The need for air dispersion modeling has increased with increasing public concern on environmental problems (United State Environmental Protection Agency, 2000; World Health Organisation, 1999, 2000, 2004). This need is even more important in developing countries due to rapid urbanization as nations forged ahead to become industrialized. According to Environment Quality Report (2003) published by Department of Environment Malaysia, SO₂ remained the main pollutant of concern in the Seberang Perai area due to industrial activities in the vicinity (Figure 1).



Source: Department of Environment, 1996-2005

Figure 1: SO₂ concentration (ppm) at Seberang Perai Station from year 1996 until 2005